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THE TARS DISTILLED FROM BITUMINOUS COAL IN HAND-FIRED FURNACES

BY

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THE TARS DISTILLED FROM BITUMINOUS COAL IN HAND-FIRED FURNACES.

By S. H. KATZ.

INTRODUCTION.

This paper, which records results of tests made as a part of the comprehensive investigation of combustion in furnaces that is being conducted by the Bureau of Mines, deals especially with the liquid or tar part, at ordinary temperatures, of the volatile matter evolved in a coal fire. Three samples of such tar were examined. The first was taken from points within a fuel bed where the coal was burning at low rates, the coal being bituminous coal from a Pennsylvania mine working the Upper Freeport bed; the second sample of tar was taken from points on the surface of a fuel bed burning at a moderately rapid rate in a large hot furnace, the coal being similar to that in the first sample; the third sample was similar to the second except for fuel being Illinois bituminous coal. The tar was collected slowly, months being required for the accumulation of the small volume of material necessary for analysis.

The results show that in the hottest fires the volatile matter evolved by the coal is the same as the so-called "primary volatile products of coal."[a] This matter after it is produced yields oxides of carbon and water vapor by burning, and forms end products—carbon or soot and fixed gases—by cracking. The two processes should be considered as acting at the same time and coordinately.

DESCRIPTION OF FURNACE FUEL BEDS FROM WHICH TAR SAMPLES WERE COLLECTED.

The tar samples tested were collected from the fuel beds of two furnaces. The general arrangement of the smaller of these is shown in Plate I.[b] The furnace consisted chiefly of a cylindrical fire pot placed on an air-tight rectangular ash box that had an orifice box attached on one side. The air was supplied under pressure through the orifice box into the ash box and up through the grate to the fuel bed. Several sampling devices were inserted radially into the furnace as shown in Plate I. These samplers were water cooled and were connected with rubber hose to a water supply and drain pipe, the latter serving also as a support for the stack. To the right is shown a table on which are gas-collecting devices.

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[a] Porter, H. C., and Taylor, G. B., The primary volatile products of the carbonization of coal: Tech. Paper 140, Bureau of Mines, 1916, 59 pp.

[b] Kreisinger, Henry, Ovitz, F. K., and Augustine, C. E., Combustion in the fuel bed of hand-fired furnaces: Tech. Paper 137, Bureau of Mines, 1916, pp. 15–17.

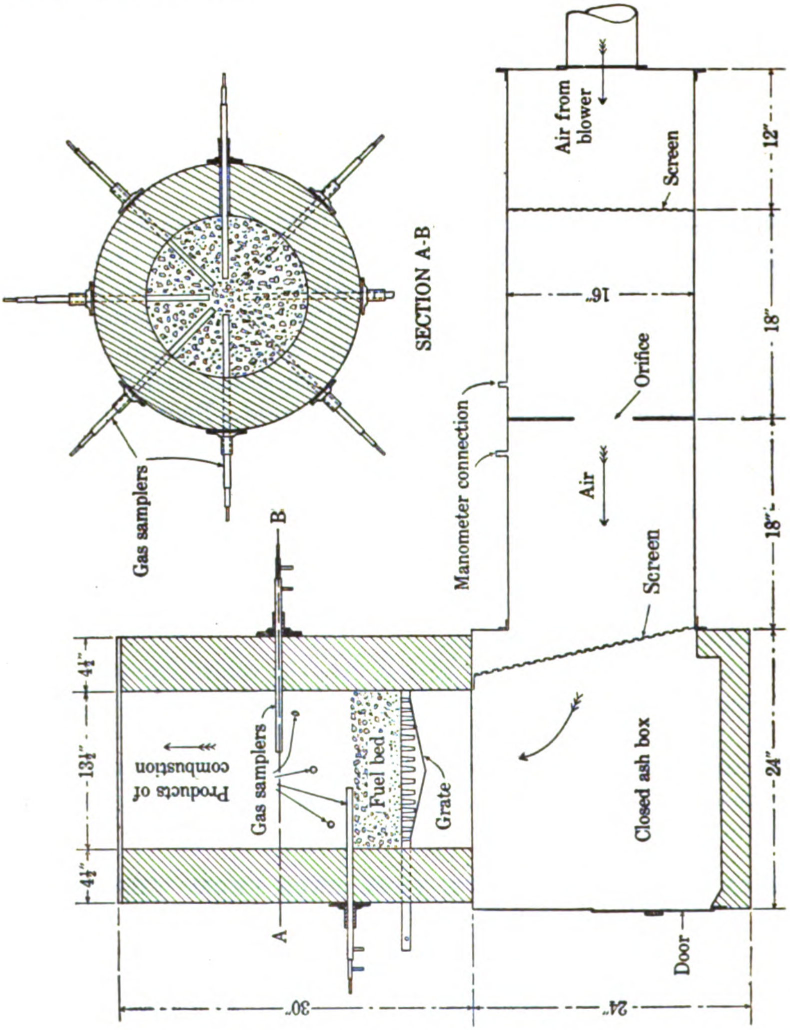
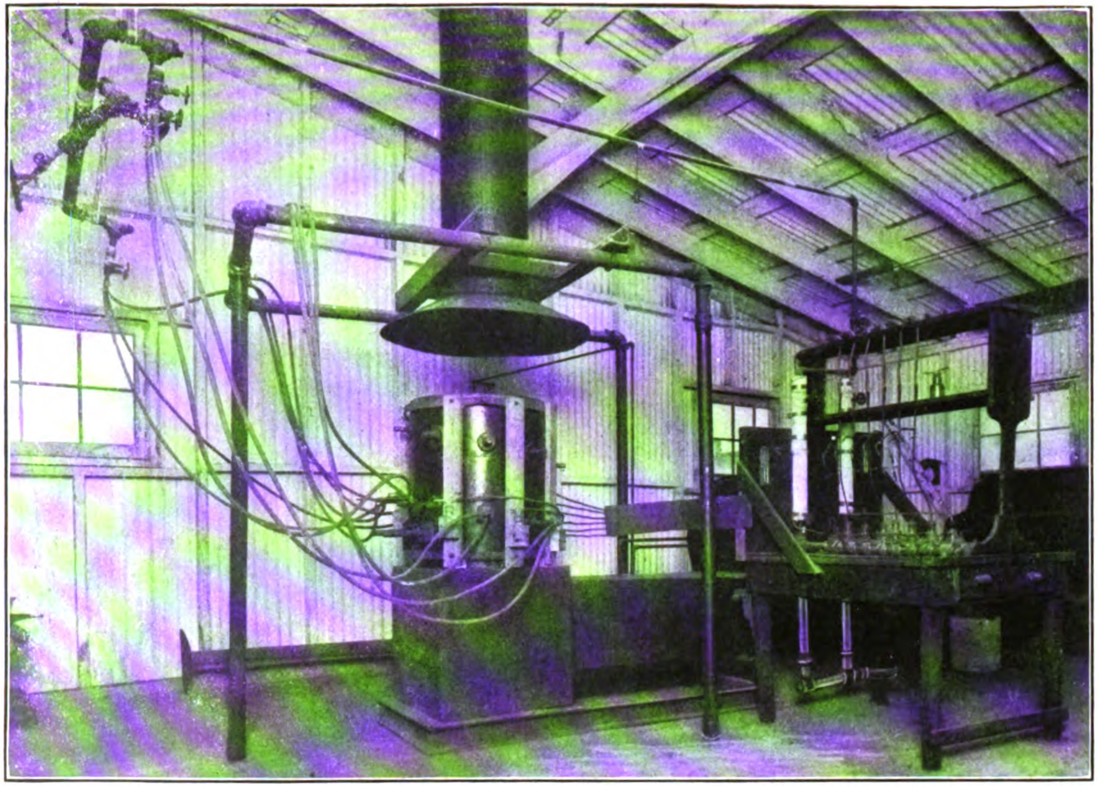


FIGURE 1.—Sections through smaller experimental furnace.

Figure 1 shows two sections through the apparatus. The furnace was a steel cylinder 22½ inches in diameter and 30 inches high, lined with a 4½-inch layer of fire brick. The space inside the lining was 13½ inches in diameter, giving approximately 1 square foot of grate area. In the wall of the furnace were several ⅝-inch holes for the insertion of samplers. The holes were in planes spaced 1½ inches



VIEW OF THE SMALLER FURNACE USED IN TESTS.

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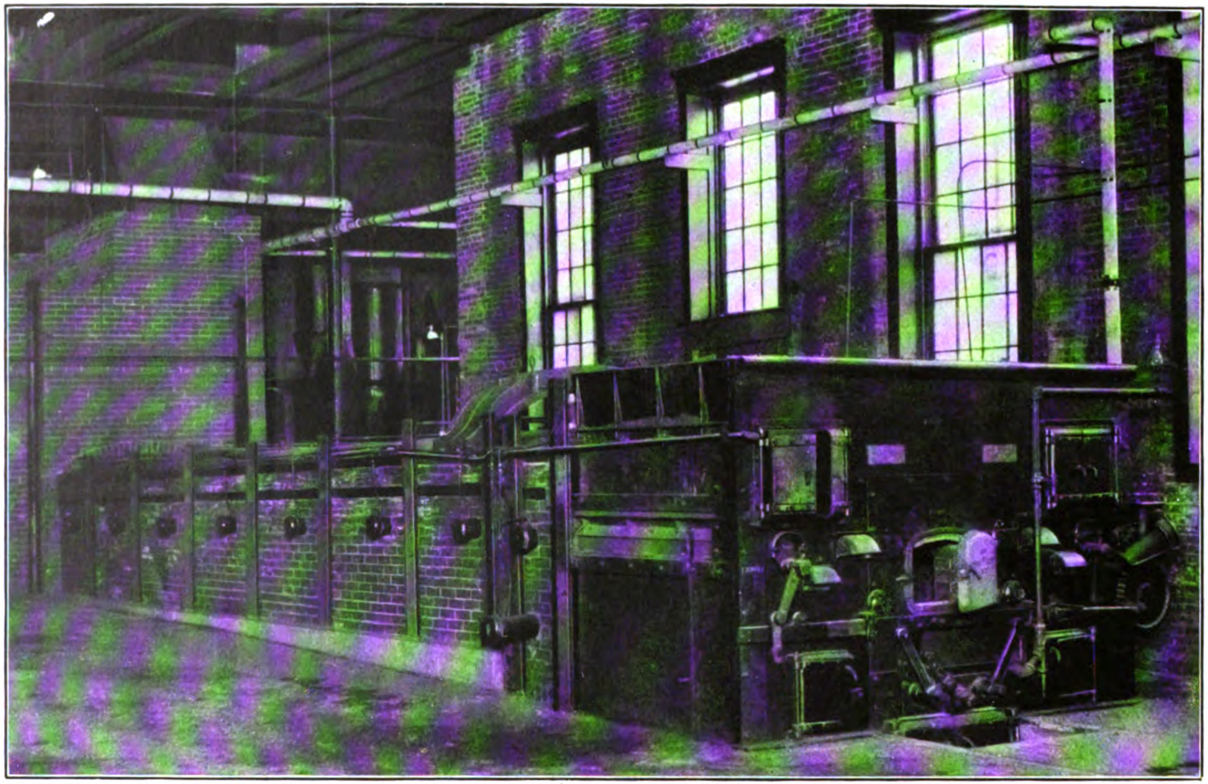

VIEW OF THE LARGER FURNACE USED IN TESTS.

apart in the vertical direction and distributed radially around the furnace, as shown in figure 1.

The grate was in two sections, each of which could be shaken independently of the other. The air spaces were about ½ inch wide and constituted approximately 60 per cent of the total grate area. The ash box had a tight-fitting door for the removal of ashes.

Upper Freeport bituminous coal was burned in this furnace at rates of 3, 6, and 10 pounds per square foot per hour. Before the tar samples were collected a bed of live coked coal 6 inches deep was obtained; then 15, 18, or 20 pounds of coal was added at one time. This was enough to burn 2, 3, or 5 hours at the rates mentioned, the conditions simulating those in house-heating furnaces.

The other furnace (Pl. II) was the "long-combustion chamber," a large furnace described in Technical Paper 63[a] and Bulletin 135[b] of the Bureau of Mines. During these investigations the furnace was equipped for hand firing and had a grate area of 30 square feet, being 5 feet wide by 6 feet deep. Coal was burned at rates varying from 20 to 60 pounds per square foot per hour. Firing was done every 2½ minutes, in uniform quantities, by a skilled and especially trained fireman. The bed was kept as nearly as possible at a depth of 6 inches. Air was supplied in measured quantities above and below the fuel bed. At the various rates of burning, tests with different excesses of air were made. The fire-box temperatures, measured with a Wanner optical pyrometer, were at times as high as 1,700° C.

COLLECTION OF SAMPLES.

TARS FROM SLOWLY BURNING UPPER FREEPORT COAL.

A few minutes after fresh coal had been added to the live coked coal in the small furnace samples of tar and included soot were collected from four points from the bottom to the top of the fresh coal. At later periods three other such sets of four samples were collected.

GAS SAMPLERS.

Water-cooled samplers[c] were used in the fuel bed. The construction of one of the gas samplers is shown in figure 2. The sampler, which was water cooled in order to prevent its destruction by heat, was made of three thin-wall copper tubes placed within one another. The joint inserted into the fuel bed was brazed; all other joints were

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[a] Clement, J. K., Frazer, J. C. W., and Augustine, C. E., Factors governing the combustion of coal in boiler furnaces: Tech. Paper 63, Bureau of Mines, 1914, p. 8.

[b] Kreisinger, Henry, Augustine, C. E., and Ovitz, F. K., Combustion of coal and furnace design: Bull. 135, Bureau of Mines, 1917, pp. 10–12.

[c] Kreisinger, Henry, Ovitz, F. K., and Augustine, C. E., Combustion in the fuel bed of hand-fired furnaces: Tech. Paper 137, Bureau of Mines, 1916, 21–22.

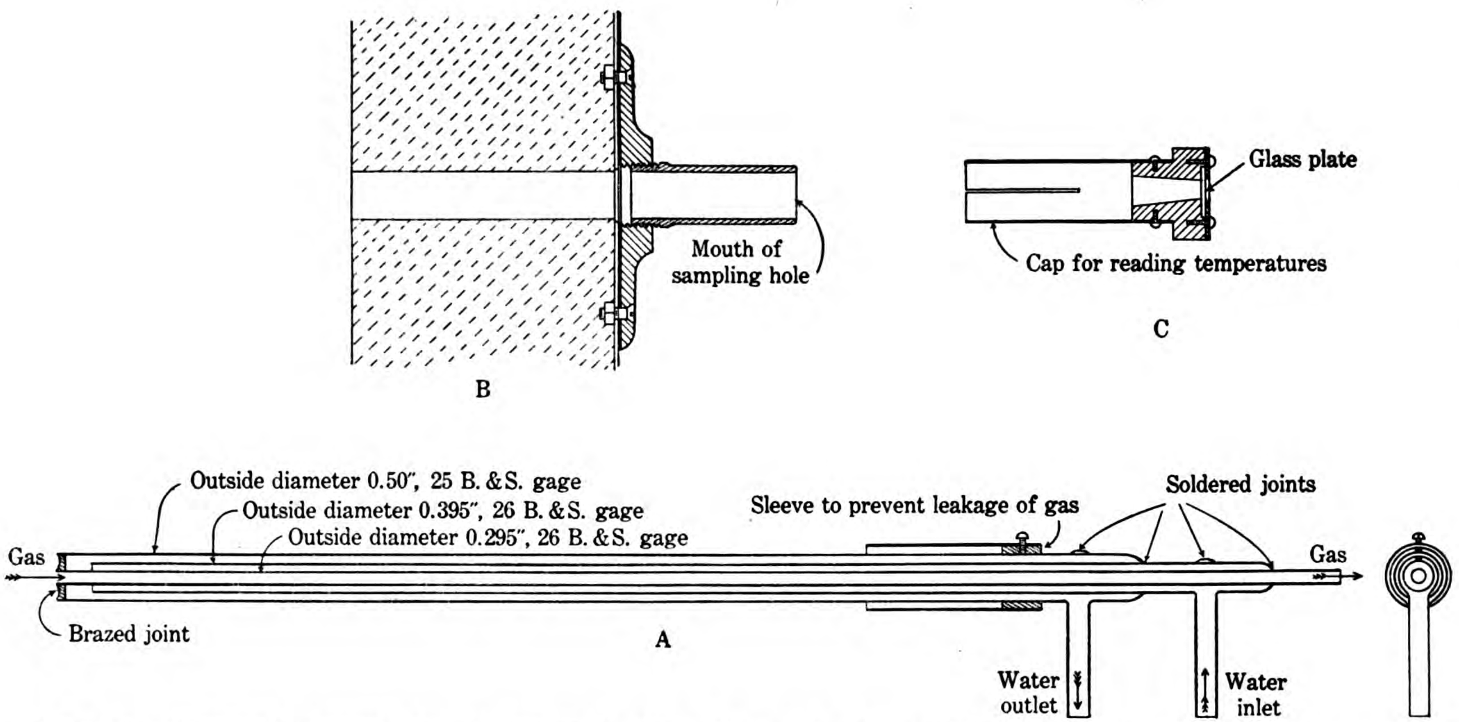
B
Mouth of sampling hole
Glass plate
Cap for reading temperatures
C
Outside diameter 0.50″, 25 B. & S. gage
Outside diameter 0.395″, 26 B. & S. gage
Outside diameter 0.295″, 26 B. & S. gage
Sleeve to prevent leakage of gas
Soldered joints
Gas
Gas
Brazed joint
A
Water outlet
Water inlet

FIGURE 2.—Arrangement of apparatus for collecting samples of gases from smaller furnace. Not drawn to scale; important details are enlarged.

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soldered. The water entered through the middle tube, which surrounded the smallest one, and left through the outer tube. A glass tube was inserted in the smallest copper tube, and the sample was drawn through this to the alundum thimble filter (fig. 3) attached to the outside end of the sampler. The gas tube was of comparatively large diameter to prevent stoppage by condensed tar and soot. The volumes of gas drawn through the sample tubes and alundum filters were measured with gas meters. The tar caught in the glass tubes and filters was taken to the chemical laboratory for further examination.

TARS FROM RAPIDLY BURNING UPPER FREEPORT COAL.

From four evenly distributed points in a plane, 6 inches above the grate of the long combustion chamber, samples of tar and soot were drawn. The plane was at or near the surface of the bed. At four similar points 18 inches above the grate, or 12 inches above the bed, four more samples were drawn. A third set of four samples was drawn from points above the bridge wall. All samples were drawn simultaneously. As with the small furnace, water-cooled samplers with glass liners and alundum filters were used to catch the tars.

TARS FROM RAPIDLY BURNING ILLINOIS COAL.

The Illinois coal was also burned in the long combustion chamber. The method of collecting samples was the same as that used in collecting samples from Upper Freeport coal burned in this furnace.

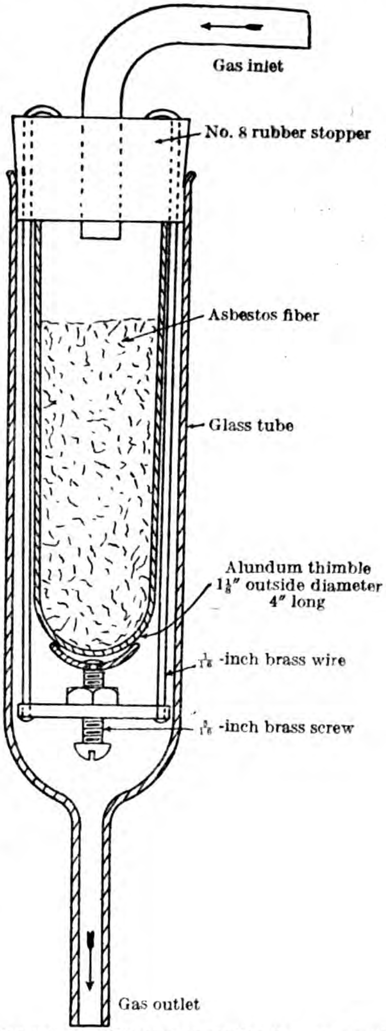
Gas inlet
No. 8 rubber stopper
Asbestos fiber
Glass tube
Alundum thimble $1\frac{1}{8}''$ outside diameter $4''$ long
$\frac{1}{16}$-inch brass wire
$\frac{3}{16}$-inch brass screw
Gas outlet

FIGURE 3.—Filter for collecting tar and soot from gases.

TREATMENT OF SAMPLES.

In the chemical laboratory the tar in the glass tubes was transferred to the respective thimbles and extracted with benzol in Soxhlet

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extractors. After extraction most of the excess benzol was distilled off. A current of air was passed over the remaining benzol and tar for three working days, or two days if the loss of weight on consecutive days was within 3 milligrams. By this process some of the lighter constituents of the tar as well as the added benzol were expelled. From the data obtained, calculations of the weight of tar per cubic foot of gas were made.

After the tar had been extracted from the contents of the alundum-thimble filters, each filter with its residue was dried and weighed, and was then ignited. The loss in weight gave data to determine the weight of soot per cubic foot of gas.

Afterwards the small quantity of tar from each sample was again dissolved in benzol and the solutions were collected until the accumulations reached the quantities used in the further investigations.

QUANTITY OF TAR IN FIRES.

Table 1, following, gives the quantities of tar in the gases within the fuel bed of the slowly burning fire.

TABLE 1.—*Quantities of tar and soot in the gases within the bed of slowly burning fires.*

[Upper Freeport bituminous coal used.]

Test No.	Rate of firing, pounds per square foot per hour.	Sample set No.	Time after firing coal.	Tar per cubic foot of gas in position [a]—				Soot per cubic foot of gas in position [a]—				Observations.
				1	2	3	4	1	2	3	4	
			H. and m.	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*	
101	[b] 3	1	0.10–0.28	1,073	812	522	108	236	84	44	16	0.17, flame appeared above bed.
		2	1.04–1.18	358	1,840	548	124	211	179	344	45	
		3	2.18–2.31	6	7	18	1	19	13	27	29	2.25, no smoke and very little flame.
		4	3.59–4.09	4	13	1	....	6	11	1	....	3.25, coal seems all coked.
102	[c] 6	1	0.05–0.17	1,580	1,805	1,722	463	67	107	95	130	0.09, first flame appears—long, yellow, smoky.
		2	0.36–0.58	467	3,397	1,238	254	82	189	506	98	
		3	1.21–1.37	5	15	9	2	5	10	51	0	1.14, short blue flame. 1.21, bed appears all coked.
		4	2.14–2.30	5	3	2	0	1	3	2	2	
103	[d] 10	1	0.05–0.16	2,280	2,490	1,750	768	235	280	249	93	0.00, flames come through and appear above bed from the start.
		2	0.31–0.46	458	1,110	17,390	118	254	244	570	96	0.31, smoky flame.
		3	1.05–1.21	6	80	1,720	102	39	29	209	132	1.01, short, yellow flame; volatile matter about exhausted. 1.21, blue flame only.
104	[c] 6	1	0.04–0.20	316	1,090	313	3,060	58	270	43	46	0.00, dense smoke arises from bed from start. 0.11, first flame appears. Smoke burns up.
		2	0.31–0.43	104	2,870	18,180	1,420	60	120	1,060	366	0.30, flame reaches 2 to 3 feet above bed.
		3	1.00–1.16	23	1,560	7,170	1,540	10	173	250	233	1.00, yellow flame 18 inches high, of small volume.
		4	1.33–1.45	2	29	2,090	56	45	77	349	89	1.30, small, thin, yellow flame. Volatile matter nearly all expelled.
105	[b] 3	1	0.04–0.20	215	784	590	204	62	90	120	32	0.00, dense, dark-gray smoke at start.
		2	0.33–0.46	521	820	456	33	42	158	65	31	0.19, first flame appears, at edges of bed only.
		3	1.06–1.20	90	1,425	3,030	370	79	138	138	96	1.06, much flame with some smoke.
		4	2.29–2.42	1	4	2	1	2	4	4	1	2.29, blue flame.

[a] 1 is at bottom of fresh coal, 4 is at top of fresh coal.

[b] 15 pounds of coal fired.

[c] 18 pounds of coal fired.

[d] 20 pounds of coal fired.

The figures show that when comparatively large quantities of fresh coal were added to slowly burning fires, the distillation of tar in fairly large quantities continued for 1½ hours or more. After 2 hours little tar was evolved.

Table 2 following shows the quantities of tar and soot found at the surface and above the surface of coal burning at moderately rapid rates in the large hot furnace.

TABLE 2.—*Quantities of tar and soot in the gases at and above the surface of the bed of rapidly burning fires.*

Test No.	Kind of coal.[a]	Rate of firing, pounds per square foot per hour.	Air excess, per cent.	Quantity of tar—average of four samples—mg. per cubic foot of gas.			Quantity of soot—average of four samples—mg. per cubic foot of gas.		
				Surface of coal.	12 inches above bed.	Above bridge wall.	Surface of coal.	12 inches above bed.	Above bridge wall.
1	2	3	4	5	6	7	8	9	10
301	Upper Freeport	20.27	50.9	16	3	2	29	95	54
302	.....do	21.54	30.91	71	3	2	149	143	98
303	.....do	24.21	—3.02	107	6	3	177	313	191
305	.....do	34.51	38.34	125	2	1	136	72	80
306	.....do	41.08	27.03	646	3	3	112	78	111
307	.....do	34.47	24.09	41	2	1	52	66	109
308	.....do	35.36	50.67	131	1	2	91	34	47
309	.....do	52.38	48.21	1,504	1	2	85	40	48
310	.....do	40.37	42.79	590	1	2	113	26	65
311	.....do	50.54	38.45	271	2	1	60	97	88
312	.....do	48.93	45.60	164	5	6	83	101	132
313	.....do	56.47	28.93	147	[b] 89	6	120	131	144
314	.....do	45.70	29.39	226	2	1	115	49	293
315	.....do	18.56	69.33	299	0	0	220	33	25
316	.....do	34.90	56.17	327	1	0	99	87	42
317	Illinois	36.54	86.61	137	1	1	214	18	12
318	.....do	37.20	72.95	359	1	1	247	54	53
319	.....do	37.12	44.88	304	1	1	400	37	57
320	.....do	38.26	14.68	281	4	2	305	151	57
321	.....do	59.03	26.69	464	0	1	297	87	37
322	.....do	59.13	27.31	229	1	1	76	36	52
323	.....do	54.4	45.0	279	0	0	232	27	16
324	.....do	20.0	52.0	120	1	1	219	36	36
325	.....do	20.0	50.0	432	1	0	62	28	26
326	.....do	20.0	40.0	119	1	1	333	40	100
327	.....do	20.0	85.0	227	0	0	215	12	11
	Total (omitting No. 313)	....	....	7,469	43	45	4,121	1,760	1,840
	Average (omitting No. 313)	....	....	287	1.7	1.7	159	68	71

[a] In this column, "Upper Freeport" represents coal from a Pennsylvania mine working the Upper Freeport bed; "Illinois." represents coal from an Illinois mine.
[b] This result probably caused by mixing of samples.

The results presented in Table 2 indicate that at the surface of the bed of a hot coal fire tar may be formed and be present in considerable quantity; that in the time required for the volatile matter to pass to a region 12 inches above the bed the tar has practically all disappeared; and that the disappearance is uniform regardless of the excess of air. Hence it may be concluded that the tar that escaped burning was decomposed to fixed gases and soot. Although a part of the tar was burned and a part decomposed by the action of the heat, the two processes take place simultaneously, and together they produce the effects that were measured. It is probable that the existence of a very small amount of tar in a region 1 foot above the bed is due to a protective coating of soot.

A series of experiments showing the quantities of tar and soot at points just above and below the surface of beds of rapidly burning Pittsburgh bituminous coal are described by Kreisinger, Ovitz, and Augustine.[a] Coal was added to the fire regularly at short intervals. The results are given in Table 3, following:

TABLE 3.—*Quantities of tar and of soot above, below, and at the surface of the bed of rapidly burning coal.*[a]

Test No.	Rate of combustion (pounds) per square foot per hour.	Tar, per cubic foot of gas (miligrams).			Soot, per cubic foot of gas (miligrams).		
		1½ inches below surface.	At surface.	1½ inches above surface.	1½ inches below surface.	At surface.	1½ inches above surface.
52	22.3	549	528	200	227	482	450
53	47.5	6	241	335	48	369	892
54	63.4	8	107	211	36	215	669
55	124	2	4	66	....	16	227
56	52	751	945	428	553	477	374
57	105.5	61	658	311	137	738	541
58	131	148	55	147	98	92	349
59	185	17	123	369	118	415	976
Total		1,542	2,661	2,067	1,317	2,804	4,478
Average		193	333	258	165	351	560
Sum of tar and soot, average		358	684	818	....	....	....

[a] Prepared from a table presented by Kreisinger, Henry, Ovitz, F. K., and Augustine, C. E., Combustion in the fuel beds of hand-fired furnaces: Tech. Paper 137, Bureau of Mines, 1916, p. 50.

The table shows that there was more tar at the surface of the bed than at points 1½ inches below or above.

RESULTS OF EXAMINATION OF TARS.

The benzol solutions of the three samples of tar collected as previously described were distilled from a 500 c.c. glass retort with a thermometer inserted, the bulb being just below the lower level of the exit tube.[b]

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[a] Kreisinger, Henry, Ovitz, F. K., and Augustine, C. E., Combustion in the fuel bed of hand-fired furnaces: Tech. Paper 137, Bureau of Mines, 1916, 76 pp.

[b] Church, S. R., Methods for testing coal tar and refined tars, oils, and pitches derived therefrom: Jour. Ind. Eng. Chem., vol. 3, 1911, pp. 227–233.

The results of the distillation are given in Table 4 following:

TABLE 4.—*Results of fractional distillation of tars.*

FRACTIONS FROM TARS FROM POINTS WITHIN FUEL BED OF SLOWLY BURNING UPPER FREEPORT COAL.[a]

Temperature.	Weight of fraction.	Percentage.	Remarks.
0° C.	*Grams.*		
100–120	7.525	11.6	Yellow, then red by oxidation; mostly added benzol.
120–170	3.955	6.1	Yellow, then red by oxidation.
170–200	.064	.1	Yellow, then black by oxidation.
200–210	.020	.0	Do.
210–235	.370	.1	Do.
235–270	1.988	3.1	Do.
270–315	10.584	16.3	Do.
315–355	4.740	7.3	Dark yellow, then black by oxidation.
Pitch residue.	36.	55.4	Black, somewhat plastic when cool, only slightly brittle.
Total	65.000	....	
FRACTIONS FROM TARS FROM POINTS AT SURFACE OF FUEL BED OF RAPIDLY BURNING UPPER FREEPORT COAL, IN HOT FURNACE.[b]			
100–120	1.525	4.9	Yellow, then red-black by oxidation.
120–170	1.364	4.4	Do.
170–200	.311	1.0	Do.
200–210	.184	.6	Do.
210–235	2.484	8.0	Do.
235–270	1.328	4.3	Do.
270–315	1.677	5.4	Do.
315–355	3.953	12.7	Do.
Pitch residue.	18.	58.7	No plasticity; very brittle, black.
Total	31.000	....	
FRACTIONS FROM TARS FROM POINTS AT SURFACE OF FUEL BED OF RAPIDLY BURNING ILLINOIS COAL, IN HOT FURNACE.[c]			
100–120	1.144	4.9	Brown, permanently.
120–170	2.919	12.4	Nearly black.
170–200	.112	.5	Black.
200–210	.226	1.0	Do.
210–235	.464	2.0	Do.
235–270	.548	2.3	Brown, then black.
270–315	2.619	11.1	Do.
315–355	2.577	11.0	Do.
Pitch residue.	12.9	54.8	Black, very brittle
Total	23.500	....	

[a] All fractions were thin liquids, mobile, and seemingly of small viscosity. When cooled below 0° C., only the first and last two showed any solidification. In the first the crystallized material was benzol. All had a cresol-like odor.

[b] All the fractions seemed much like those previously described, in appearance and odor, and when subjected to freezing.

[c] In odor and mobility all fractions were the same as those previously described. All were discolored by slight spattering. No freezing tests were made.

Further examination was then made of a part of the tars obtained from the slowly burning fires, and of a part from the rapidly burning fires. From the slowly burning fires the fraction of distillate evolved between the temperatures 270° and 315° C. was used. From the rapidly burning fires all the distillates between the temperatures of 210° and 355° C. from both the Upper Freeport and the Illinois coals were mixed together and examined. The results of such examination are given in Table 5 following:

TABLE 5.—*Results of examination of tar distillates.*

Item.	Fraction at 270° to 315° C. from tars from slowly burning fires.	Fraction at 210° to 355° C. from tars from rapidly burning fires.	Remarks.
Specific gravity $\left(\frac{15^\circ}{15^\circ}\text{C.}\right)$	0.970	....	
Refractive index	[a] 1.541	[b] 1.578	
Iodine number	75.0	....	Determination made by H. H. Hill.
Analysis:			
Carbon .... per cent	85.70	(c)	Oxygen determined by difference. **This gives the empirical formula C $_{(5.95=6)}$H$_{(8.00)}$O$_{(0.25)}$. Analysis by F. D. Osgood.**
Hydrogen .... do	9.60		
Oxygen .... do	4.70		
Tar acids .... do	25	33	Determined by treatment of oils with 10 per cent NaOH solution in graduated separatory funnel. To obtain 25 per cent figure, 10.1 c. c. of oil was used. On redistillation the acids cracked badly, formed a more viscous liquid than the original, and turned black on oxidation after distillation. To obtain the 33 per cent figure, 12.1 c. c. of oil was used. The acids were recovered and not distilled. They formed a thick, black liquid and had the characteristic odor.
Bodies separable by freezing, per cent.	5	(c)	Acid-free oil was cooled to −15° C. The separated solid was removed as completely as possible by decantation. It was a yellow solid, forming a dark yellow oil at ordinary temperatures. The color was permanent.
Unsaturated aliphatic bodies, per cent.	9	26	Residues from previous determinations were treated at ordinary temperature with H_2SO_4 having a specific gravity of 1.84. Three treatments were made. For the 9 per cent recovery, 45 c. c. of acid was used. The oil recovered formed a thick nearly black liquid. For the 26 per cent recovery, 75 c. c. of acid was used. The oil recovered formed a thick, dark-red liquid.
Saturated aliphatic bodies, per cent.	16	17	Residues from previous determinations were treated with 20 c. c. of 37 N., slightly fuming H_2SO_4 at 100° C. for 1 hour, with shaking every 10 minutes. Solutions were then diluted with water, and the unattacked oils extracted with ether and recovered. The 16 per cent extraction was a thin, water-white liquid, with a pleasant ethereal odor. It did not change color on standing. The 17 per cent extraction was a thin, red-brown oil, with a pleasant ethereal odor. The color was due to cracking by distillation.
Aromatic bodies....per cent	45	24	Results obtained by difference. Sulphonated bodies in the fraction from the tar from slowly burning fires were soluble in water. They were not recovered. A water solution of the sulphonated bodies in the fraction from the tar from rapidly burning fires was made alkaline with Na_2CO_3 and evaporated to dryness; the sulphonic salts were extracted with absolute alcohol and evaporated to dryness. Light-brown crystalline salts were recovered.

[a] At 23° C.

[b] For fraction at 270° to 315° C. of tar from Illinois coal, at 20°.

[c] Test not made.

The results of separating tar oils into the various constituents of tar acids, unsaturated bodies, saturated aliphatic bodies, and aromatic bodies are rather inexact, especially the separation of the unsaturated bodies and the aromatic bodies. Also, the small quantity of material available in this work made the separations difficult and less accurate. For these reasons only qualitative values should be put upon the figures in Table 5 showing percentages of the various oil constituents.

By distilling coal at low temperatures, under conditions that yield the primary distillation products without change, Jones and Wheeler[a] found that the yield of tar was 6.5 per cent of the weight of bituminous coal. Of this tar 50 per cent was a pitch residue and 50 per cent an oil separated by distillation to 300° C. The oil consisted of 40 to 45 per cent of ethylenic hydrocarbons; 40 per cent of naphthenes and liquid paraffins, the former greatly predominating; 12 to 15 per cent of phenols, chiefly cresols and xylenols; 7 per cent of aromatic hydrocarbons, seemingly homologs of naphthalene, though no naphthalene appeared to be present; a solid paraffin in small quantity; benzine and its homologs, anthracene, carbon disulphide, and solid aromatics were absent.

Qualitatively the tars obtained from the fires were much the same as Jones and Wheeler's "primary volatile matter." Naphthalene and anthracene are characteristic of the thermal decomposition at intermediate temperatures of the primary distillation products of coal. No naphthalene or anthracene in the tar from the fires could be recognized either by the freezing test or by odor.

SPEED OF REACTIONS OF TARS IN FIRES.

The greatest proportion of tar vapors exists at the surface of the bed of burning coal; in a plane 1 foot above the bed practically no tar remained, no matter what the excess of air mixed with the combustible gases above the bed. The rapidity of the breaking up of the tars to form soot and fixed gases may be judged by considering the tabulated data in connection with the speed of travel of the gases.

Coal was burned at the rate of nearly 60 pounds per square foot per hour. To burn this coal $60\times7=420$ pounds, or 5,460 cubic feet of air at ordinary temperatures, was forced through each square foot of bed per hour. At 1,600° C. this gas would expand to 34,900 cubic feet. This means that the gases travel at the rate of at least 34,900 feet per hour, or 9.7 feet per second. The gases pass the first foot above the bed in $1\div9.7=0.103$ second. During this time all the tars are decomposed.

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[a] Jones, D. T., and Wheeler, R. V., The composition of coal: Jour. Chem. Soc., vol. 105, 1914, pp. 141–151.

A considerable proportion of air was mixed with the gases above the fuel bed, and also the volume of gas rising from a burning bed is greater than that of the air passed through the coal. Hence, on the basis of experimental evidence, it may be stated that the tars can exist in the fires of a hot furnace burning bituminous coal for a period that is less than 0.1 second.

CONCLUSIONS.

1. When bituminous coal in quantities to last for a period of hours is added to a slowly burning fire, tar may be found in the gases within the fuel bed through a considerable part of the time the coal is burning.
2. When coal is added to fires in uniform quantities and at short, regular intervals, the greatest quantity of tar in the gases is at the surface of the bed.
3. At a point 1 foot above the bed of bituminous coal burning in a large, hot furnace at moderately rapid rates, practically all tar had disappeared.
4. Naphthalene and anthracene, which, at intermediate temperatures, are characteristic of the thermal decomposition of the primary volatile matter of coal, were absent from the tars collected.
5. It is probable that, at the high temperatures of flames, the tars that escape burning are decomposed directly to soot and fixed gases; that is, without formation of hydrocarbons, such as naphthalene and anthracene, which are produced as intermediates, at least in part, at lower temperatures.
6. Decomposition of all the unburned tars in hot fires to soot and fixed gases occurs in less than 0.1 second.

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